

# **NASA Contractor Report 181896**

## **Residual Interference Assessment in Adaptive Wall Wind Tunnels**

**A. V. Murthy**  
**Vigyan Research Associates, Inc.**  
**Hampton, VA 23666-1325**

**Contract NAS1-18585**  
**September 1989**



National Aeronautics and  
Space Administration

**Langley Research Center**  
Hampton, Virginia 23665-5225

**(NASA-CR-181896) RESIDUAL INTERFERENCE  
ASSESSMENT IN ADAPTIVE WALL WIND TUNNELS  
(Vigyan Research Associates) 32 p CSCL 14B**

**N90-12625**

**Unclas**  
**G3/09 0240383**



# **RESIDUAL INTERFERENCE ASSESSMENT IN ADAPTIVE WALL WIND TUNNELS**

## **SUMMARY**

A two variable method suitable for on-line calculation of residual interference in airfoil testing in the Langley 0.3-m Transonic Cryogenic Tunnel (0.3-m TCT) is described. The method applies the Cauchy's integral formula to the closed contour formed by the contoured top and bottom walls, and the upstream and downstream ends. The measured top and bottom wall pressures and position are used to calculate the correction to the test Mach number and the airfoil angle of attack. Application to specific data obtained in the 0.3-m TCT adaptive wall test section demonstrates the need to assess residual interference to ensure the desired level of wall streamlining is achieved. A Fortran computer program has been developed for on-line calculation of the residual corrections during airfoil tests in the 0.3-m TCT.

## **INTRODUCTION**

Transonic wind tunnels with conventional ventilated walls for the test section have large wall interference effects, often of uncertain magnitude. Recent developments in adaptive wall technology eliminates or reduces the undesirable wall effects by active control of the flow conditions at the test section boundaries. By moving or controlling the flow through the test section walls, the confining effect of the tunnel walls over the model is reduced. The various methods of achieving unconfined or free air conditions at the wall, and the present state of the art of adaptive wall wind tunnels are described in a number of recent reviews<sup>1,2</sup>.

The establishment of free air flow conditions at the wall eliminates the interference effects on the model measurements. Hence, in principle, the data obtained from adaptive wall wind tunnels correspond to almost free air conditions with negligible residual interference. However, several factors such as approximations in the technique of adjusting conditions at the walls, control at a finite number of wall locations and complex flow situations at high angles of attack introduce departure from ideal conditions. Therefore, it is desirable to assess residual wall interference, if any, as a part of the adaptive wall testing technique. Such calculations help in achieving the desired level of wall adaptation and also aid in interpreting the test data for flow situations with less than desired level of wall adaptation.

Several methods exist for the evaluation of two-dimensional wall interference<sup>3</sup>. These methods use the measured flow conditions at the boundary in lieu of the classical homogeneous boundary

conditions. When only one measurement is available at the walls, the interference calculation requires a knowledge of the model forces<sup>4,5</sup>. This method is suitable for ventilated wall tunnels where it is difficult to measure flow directions and only pressure measurements are made. When both the wall pressure and flow direction are known as in the case of adaptive wall tunnels, the model representation is unnecessary. These measurements are available as a part of the adaptive wall adjustment procedure. The two variable method is particularly useful when the model size is large compared to the test section size. The vortex and doublet representation of the model in the single variable method becomes inaccurate with a large model. A detailed description of these methods is given by Mokry<sup>3,6</sup>.

The present report studies the application of the two variable method with particular reference to the Langley 0.3-meter Transonic Cryogenic Tunnel (0.3-m TCT) adaptive wall test section. This method independently suggested by Ashill and Weeks<sup>7</sup>, and by Smith<sup>8</sup> uses the Cauchy's integral formula. Ashill and Weeks applied the method to correct the model data from measured pressures along the straight walls of a solid wall tunnel. The method is quite general, and particularly suitable for application to curved wall contours formed by the top and bottom walls in an adaptive wall wind tunnel using solid flexible plates. The calculations take into account the curved contour without the need for small disturbance approximation. This will be advantageous when the wall deflections are large with relatively large model sizes.

The motivation for undertaking the present work was to quantify the level of interference in the 0.3-m TCT airfoil test data. Experience during different entries (reference 9) of a 9-inch chord super-critical airfoil had indicated severe lack of repeatability of test data with the technique of wall adjustment used in the 0.3-m TCT. Some salient results of the application of the two variable method are given in reference (9). The method was useful in identifying and discriminating test data having large residual interferences. The present report gives briefly the details of the method and its specific application to the 0.3-m TCT test data.

## NOMENCLATURE

A	area of cross-section
a	speed of sound
b	test section width
c	airfoil chord
$c_l$	lift coefficient

$c_p$	pressure coefficient
$h$	test section height (with straight walls)
$M$	local Mach number
$p$	pressure
$U$	local velocity
$u$	streamwise component of the perturbation velocity
$v$	normal component of the perturbation velocity
$W$	complex velocity ( $\beta u - iv$ )
$x$	streamwise coordinate
$y$	normal coordinate
$Z$	top and bottom wall deflection from straight position
$z$	complex variable ( $x+iy$ )
$\beta$	compressibility factor, $= [1-M_\infty^2]^{1/2}$
$\gamma$	ratio of specific heats
$\Delta M$	correction to freestream Mach number
$\Delta \alpha$	correction to angle of attack
$\zeta$	complex coordinate along closed contour ( $\xi+i\eta$ )
$\mu$	doublet strength
$\Gamma$	vortex strength

#### subscripts

$t$	stagnation conditions
$w$	wall induced interference quantities
$\infty$	freestream conditions

### ANALYSIS

The details of calculating the interference velocity using the Cauchy's integral formula are presented in a number of reports cited earlier. The method calculates the wall induced velocities at the model station by integrating the measured velocities along the closed contour  $\Gamma$  (fig 1) formed by the curved top and bottom walls, and the upstream and downstream ends of the test section. The complex wall induced interference velocity  $W_w$  at an interior point  $z$  within the closed contour is given by

$$W_w(z) = \frac{1}{2\pi i} \int_{\Gamma} \frac{W(\zeta)}{(\zeta - z)} d\zeta \quad (1)$$

where

$$W_w(z) = \beta u_w(x,y) - i v_w(x,y) \quad (2)$$

$$z = x/\beta + iy \quad (3)$$

$$\zeta = \xi/\beta + i\eta \quad (4)$$

The complex interference velocity  $W_w(z)$  at the interior point  $z$  is calculated by integrating the measured perturbation velocities  $W(\zeta)$  along the closed contour  $\Gamma$ . The term  $\beta$  represents the correction for compressibility effect through Prandtl-Glauert factor. The longitudinal and vertical components of the interference velocity are then given by the real and imaginary parts of the complex velocity  $W_w(z)$ .

$$u_w(x,y) = (1/\beta) \operatorname{Re} W_w(z) \quad (5)$$

$$v_w(x,y) = - \operatorname{Im} W_w(z) \quad (6)$$

Representing the streamwise and normal components of the velocity along the contour  $\Gamma$ , by  $u(\xi,\eta)$  and  $v(\xi,\eta)$ , and simplifying equation (1), we get

$$u(x,y) = - \frac{1}{2\pi\beta} \int_{\Gamma} \frac{[(\xi-x)v(\xi,\eta) + \beta^2(\eta-y)u(\xi,\eta)]d\xi - \beta^2[(\xi-x)u(\xi,\eta) - (\eta-y)v(\xi,\eta)]d\eta}{(\xi-x)^2 + \beta^2(\eta-y)^2} \quad (7)$$

$$v(x,y) = \frac{\beta}{2\pi} \int_{\Gamma} \frac{[(\xi-x)u(\xi,\eta) - (\eta-y)v(\xi,\eta)]d\xi + [(\xi-x)v(\xi,\eta) + \beta^2(\eta-y)u(\xi,\eta)]d\eta}{(\xi-x)^2 + \beta^2(\eta-y)^2} \quad (8)$$

The expressions (7) and (8) give the interference velocities at any interior point  $(x,y)$  within the boundaries formed by the test section top and bottom walls, and the upstream and downstream ends. Of particular interest is the correction at the origin corresponding to the airfoil quarter chord point. The corrections to the test Mach number  $M_{\infty}$  is given by

$$\Delta M = (1 + 0.2 M_{\infty}^2) M_{\infty} u_w(0,0) \quad (9)$$

The correction to the flow inclination at the quarter chord point is given by the non-dimensional vertical interference velocity  $v_w(0,0)$ .

The application of the method to streamlined wall wind tunnels is straight forward. The pressure measurements along the walls and the local wall slopes determine both the horizontal and vertical velocity distributions. Allowance for the boundary-layer growth can be made by adding the displacement thickness distribution to the wall contour. The integration can then be carried out along the closed contour to determine the interference corrections. For adaptive wall tunnels using porous walls with segmented plenums, the velocity measurements are usually made along a straight line away from the walls.

The equations (8) and (9) are applicable as long as the flow at the wall is subsonic. This condition is satisfied in most cases even with large regions of supercritical flow over the airfoil. The integration along the contour requires distribution of the perturbation velocities along the upstream and downstream ends of the test section. Usually, in many wind tunnels the measurements are made over a finite distance on the top and bottom walls only. Hence, either interpolation or extrapolation of the measured pressures is often necessary. This is true for all the interference calculation as well as wall adjustment methods.

An interesting feature of the method is the auto-corrective property for the Mach number correction. The method accounts for small variations in the measurement of reference test Mach number and is nearly independent regarding where the reference Mach number is measured in the test section. The difference between the reference Mach number and the true Mach number appears as a corresponding Mach number correction. This property is useful particularly in adaptive wall tunnels where it is often difficult to get a true measurement of the test Mach number particularly in the presence of large models. Also, small changes in the reference Mach number do not significantly affect the correction to the angle of attack. This auto -corrective property is demonstrated by Mokry in references (3) and (6).

## RESULTS AND DISCUSSION

### Method of Calculation:

The top and bottom wall pressure coefficients are first converted to local velocities using the reference Mach number and the stagnation conditions. The local Mach number ( $M$ ) in terms of the pressure coefficient ( $c_p$ ) is calculated from the isentropic relations (for  $\gamma=1.4$ )

$$M = [5(p_t/p)^{2857} - 1]^{1/2} \quad (10)$$

$$p_t/p = (p_\infty/p) [1 + 0.2M_\infty^2]^{3.5} \quad (11)$$

and

$$p/p_\infty = 1 + 0.7c_p M_\infty^2 \quad (12)$$

The local velocity (U) is given by

$$U = M a_t [1 + 0.2M^2]^{-1/2} \quad (13)$$

where  $a_t$  is the speed of sound corresponding to stagnation conditions.

The local wall slopes are then determined by fitting a cubic spline curve to the wall shapes and the tangential velocity resolved into horizontal and vertical components  $u$  and  $v$ . Knowing the velocity components, the corresponding values of the integrand in the velocity integrals (7) and (8) were then evaluated at each measurement station. The velocity integrals were then evaluated to give the interference velocities at the location  $(x,y)$ . The integration along the contour was split into four parts; corresponding to top and bottom walls, upstream end and downstream end. The values across the upstream and downstream ends were approximated by linearly interpolating the local top and bottom wall values.

A Fortran-5 computer program incorporating the above procedure was developed. The program was initially used off-line to assess wall corrections to the airfoil data obtained in the 0.3-m TCT adaptive wall test section. The details of input data to the program and a sample output are given in Appendix A.

#### Test Cases:

The computer program was checked by simulating the flow within a solid straight wall wind tunnel for the case of a point vortex and a point doublet located midway between two horizontal walls. For a line vortex (fig 2), the velocity distribution on the top and bottom walls is given by

$$u(x, \pm h/2) = \pm(\Upsilon/2h) [\cosh(\pi x/h)]^{-1} \quad (14)$$

where  $\Upsilon$  is the vortex strength. For an airfoil of chord  $c$ , at a lift coefficient  $c_l$  in a stream of velocity  $U_\infty$ , the equivalent vortex strength will be  $cc_l U_\infty/2$ . The calculated velocity distribution for a lift coefficient of 0.5,  $c=6.5"$  and  $h=13.0"$  is shown in figure 3. The values on the top and



bottom walls are equal but of opposite sign. Using this velocity distribution as input, the wall induced interference velocities were calculated from the computer program. The upwash distribution along the tunnel centerline and its comparison with the exact potential flow solution is shown in figure 4. The good comparison indicates that the errors involved in averaging the data at the upstream and downstream ends are not significant. The exact potential flow upwash distribution was obtained by considering the doubly infinite image system of vortices.

A similar case with a point doublet representing the blockage effects is shown in figures 5 and 6. The velocity induced due to a point doublet at the origin is given by

$$u(x,y) = (\mu/2\pi\beta) (\beta^2 y^2 - x^2) / (x^2 + \beta^2 y^2)^2 \quad (15)$$

where  $\mu$  is the doublet strength. For an equivalent cylinder of cross-sectional area  $A$ , the doublet strength  $\mu$  is equal to  $2AU_\infty$ . The velocity distribution on the walls of the simulated wind tunnel will be that due to the doublet and its doubly infinite image system. Figure 5 shows the velocity induced on the top and bottom walls for a cylinder of 2-inch radius in a test section of height 13 inches. The computed blockage velocities (figure 6) on the tunnel centerline agree with the exact calculation using the image system.

#### Application to 0.3-m TCT data:

Figure 7 shows a schematic arrangement of the 0.3-m TCT adaptive wall test correction. The description and the operational characteristics of the 0.3-m TCT adaptive wall test section are given in reference (10). The top and bottom flexible walls are anchored at the upstream end. Twenty-one jacks on each wall support the flexible walls and provide the wall streamlining capability. The wall pressures are measured at each of the jack stations. The wall geometry and the measured pressures are used in an iterative manner to determine the streamline shapes<sup>11,12</sup>. The reference Mach number is measured on the top wall at the entry to the test section. This location is at a distance of 31.25 inches ( $\approx 2.5h$ ) upstream of the model location. The first eighteen jacks on each wall (covering a length of about 52 inches) are used in the streamlining calculation. The last three jacks provide a smooth entry to the tunnel diffuser.

To demonstrate the application of the method to the 0.3-m TCT test data, two examples corresponding to fully adapted wall conditions have been considered. The first example refers to the data on a short 6.5" chord laminar flow airfoil ( $c/h = 0.5$ ). The corresponding wall pressures and wall displacements shown in figures 8a and 8b, have been incorporated as default values in the computer program. The test Mach number is 0.5. The calculated blockage effect along the center line is shown in figure 9a. The correction to Mach number is negligible with a maximum value of about 0.002 near the model region. The upwash distribution or the correction to the angle of attack (figure 9b) is not uniform across the airfoil chord. However, the correction is still small considering the other uncertainties in the tests.

The second example refers to a relatively large chord ( $c=13.0"$ ) super-critical airfoil at a Mach number of 0.764. The flow over the airfoil has large supersonic region while the flow at the wall is still subsonic. The corresponding wall pressures and displacements are shown in figures 10a and 10b. The reference Mach number for this case was measured at the most upstream location (figure 7). Figure 11a shows the blockage velocity distribution along the centerline. The blockage is not uniform over the chord, and the correction to the Mach number at the quarter chord point is about 0.008. The corresponding upwash velocity distribution (figure 11b) is nearly linear over the chord. The correction to the angle of attack at the quarter chord point is less than 0.1 deg.

The upwash distribution in both cases suggests that while the correction to the incidence is small, it may be necessary to examine the streamline curvature corrections. This is obtained by calculating the gradients  $\partial v/\partial x$  from equation (8). The large correction to the test Mach number noted in the second example demonstrates the need for examining the residuals to ensure the adequacy of wall streamlining. However, it must be noted that with the adaptive capability of the walls, it is possible to reduce the corrections to much lower levels ( $\Delta M \approx 0.002$ ).

The principles underlying the wall adaptation methods and the interference assessment are similar. The Cauchy's integral formula can also be used to determine the wall movements required to obtain free air conditions in the tunnel<sup>13</sup>. With combined application of the interference calculation and the wall movements using the Cauchy's integral formula, it is possible to reduce the corrections to the desired level. This approach helps in achieving nearly free air conditions in the tunnel to a level consistent with approximations involved in wall adaptation and interference assessment methods. The application of the combined approach to the 0.3-m TCT adaptive walls will be examined in a separate report.

**On-line operation:**

The motivation for undertaking this work was to quantify the level of interference in 0.3-m TCT airfoil test data. Experience during different entries (reference 9) of a 9-inch chord super-critical airfoil had indicated severe lack of repeatability of test data with the technique of wall adjustment used in the 0.3-m TCT. Therefore, a version of the program developed was installed on a Micro-Vax computer for on-line calculation of the residual wall interferences for airfoil tests in the 0.3-m TCT. The program is now operational and is available for routine use with airfoil test. The details of the computer program and its on-line operation will be given in a separate report.

**CONCLUDING REMARKS**

A two variable method suitable for on-line calculation of residual interference in airfoil testing in the Langley 0.3-m Transonic Cryogenic Tunnel (0.3-m TCT) has been developed. The method applies the Cauchy's integral formula to the closed contour formed by the contoured top and bottom walls, and the upstream and downstream ends. The measured top and bottom wall pressures and position are used to determine the correction to the test Mach number and the airfoil angle of attack. Application to specific data obtained in the 0.3-m TCT adaptive wall test section demonstrate the need to assess residual interference to ensure the desired level of wall streamlining is achieved. A Fortran computer program has been developed for both on-line and off-line calculation of the residual corrections for airfoil tests in the 0.3-m TCT.

## REFERENCES

1. Ganzer, U.: A Review of Adaptive Wall Wind Tunnels. *Prog. in Aerospace Sci.*, Vol. 22, 1985, pp 81-111.
2. Davis, S. S: The Evolution of Adaptive Wall Wind Tunnels. In: *Recent Advances in Aerodynamics*. New York, Springer-Verlag, 1983, pp 547-566.
3. Mokry, M.; Chan, Y. Y.; and Jones, D. J.: Two-Dimensional Wind Tunnel Wall Interference. Edited by Ohman, L. H. AGARDograph No. 281, November 1983.
4. Capalier, C; Chevallier, J. P.; and Buinol, F.: A New Method for Correcting Two-Dimensional Wall Interference. *La Recherche Aerospatiale*, Vol. 22, Jan/Feb 1978, pp 1-11.
5. Murthy, A. V.: A Simplified Fourwall Interference Assessment Procedure for Airfoil Data Obtained in the Langley 0.3-Meter Transonic Cryogenic Tunnel. NASA CR-4042, Jan 1987.
6. Mokry, M.: Residual Interference and Wind Tunnel Wall Adaptation. Paper presented at the CAST 10-2/DOA2 Airfoil Workshop at NASA Langley Research Center, Hampton, Virginia. September 23-27, 1988.
7. Ashill, P. R.; and Weeks, D. J.: A Method for Determining Wall Interference Corrections in Solid-Wall Tunnels from Measurement of Static Pressures at the Walls. AGARD-CP-335, May 1982, pp 1.1-1.12.
8. Smith, J.: Measured Boundary Conditions for 2D Flow. AGARD-CP-335, May 1982, pp 9.1-9.15.
9. Murthy, A. V.; and Ray, E. J.: Experience with Some Repeat Tests on the 9-inch Chord CAST 10-2/DOA2 Airfoil Model in the Langley 0.3-M TCT Adaptive Wall Test section. Paper presented at the CAST 10-2/DOA2 Airfoil Workshop at NASA Langley Research Center, Hampton, Virginia. September 23-27, 1988.
10. Ladson, C. L; and Ray, E. J.: Evolution, Calibration and Operational Characteristics of the Two-Dimensional Test Section of the Langley 0.3-Meter Transonic Cryogenic Tunnel. NASA TP 2749, Sept. 1987.
11. Judd, M.; Goodyer, M. J.; and Wolf, S. W. D.: Application of the Computer for On-site Definition and Control of Wind Tunnel Shape for Minimum Boundary Interference. Presented at AGARD Specialists' Meeting on "Numerical Methods and Wind Tunnel Testing". Rhode-Saint-Genese, Belgium., in AGARD-CP-210, October 1976, paper no. 6, 14pp.
12. Wolf, S. W. D.; and Ray, E. J.: Highlights of Experience with a Flexible Walled Test Section in the NASA Langley 0.3-Meter Transonic Cryogenic Tunnel. AIAA Paper No. 88-2036, May 1988.
13. Everhart, Joel, L.: A Method for Modifying Two-Dimensional Adaptive Wind-Tunnel Walls Including Analytical and Experimental Verification. NASA Technical Paper 2081, Feb. 1983.

## APPENDIX A

### Input Data

The sequence of input data the computer program for post-test calculation of the interference corrections is as follows.

Record 1: TITLE CARD  
Record 2: 00  
Record 3: \$IDATB IECHO=0, IPR=0, \$END

The first record corresponds to the title. This information is reproduced in the output. The second record contains either "00" or "01" in the first two columns depending on whether the wall information is given as pressure coefficients or as perturbation velocities respectively. The remaining data is input through the namelist \$IDATB. The various parameters and their default values in the namelist are:

### Namelist \$IDATB

ITEST: Test number (999),  
IRUN: Run number (999),  
IPOINT: Point number(999),  
IECHO: = 1, Input data appears on output  
          = 0, Input data does not appear on output (0),  
ITYPE: = 1, Wall velocities are specified  
          = 0, Wall pressure coefficients specified (0),  
NJT: Number of measurement points, top wall (19),  
NJB: Number of measurement points, bottom wall (19),  
NJU: Number of measurement points, upstream (9),  
NJD: Number of measurement points, downstream (9),  
NT: No. of locations for calculation, top wall (19),  
NB: No. of locations for calculation, bot wall (19),  
NU: No. of locations for calculation, upstream (2),  
ND: No. of locations for calculation, downstream (2),  
IBL: for future use (1),

IPR:       = 1, output of intermediate calculations  
           = 0, final results,  
 EMINF:    freestream Mach number (0.501),  
 TTINF:    stagnation temperature, rankine (540),  
 XSTART:   starting point for integration (-31.25),  
 XEND:      end point for integration    ( 20.75),  
 CHORD:    airfoil chord, inches        ( 6.50),  
 WIDTH:    testsection width, inches    ( 13.00),  
 ZTOP:      location of top wall from airfoil plane ( 6.50),  
 ZBOT:      location of bottom wall from airfoil plane(-6.50),  
 XLE:       distance between turntable center and airfoil leading edge (3.0),  
 ISWL:      for future use (= 0),  
 XT:        x coordinate of measurement location on top wall  
           (= -31.25,-26.00,-20.25,-15.25,-11.25,-8.25,-6.25,-4.75,-3.25,-1.75,  
           -0.25,1.25,2.75,4.75,6.75,8.75,11.75,15.75,20.75,25.75,30.75,36.75,  
 XB:        x coordinate of measurement location on bottom wall  
           (= -31.25,-26.00,-20.25,-15.25,-11.25,-8.25,-6.25,-4.75,-3.25,-1.75,  
           -0.25,1.25,2.75,4.75,6.75,8.75,11.75,15.75,20.75,25.75,30.75,36.75,  
 ZT:        top wall displacements (inches)  
           (=.0000,.0267,.0656,.1111,.1800,.2271,.2801,.3186,.3518,.3779,  
           .3909,.3870,.3694,.3417,.3129,.2930,.2762,.2471,.1988,  
 ZB:        bottom wall displacements (inches)  
           (=.0000,.0075,.0116,.0300,.0307,.0307,.0197,.0152,.0095,.0068,  
           .0048,.0102,.0069,.0017,-.0126,-.0330,-.0662,-.1104,-.1347,  
 CPT:       top wall pressure coefficients  
           (=-.0080,.0012,.0028,.0021,-.0166,-.0051,-.0297,-.0449,-.0575,  
           -.0701,-.0741,-.0626,-.0509,-.0304,-.0180,-.0118,-.0268,-.0084,-.0029,  
 CPB:       bottom wall pressure coefficients  
           (=.0275,.0102,.0112,.0148,.0144,.0311,.0133,.0278,.0230,.0288,  
           .0367,.0551,.0386,.0378,.0310,.0271,.0071,.0064,.0016,  
 XU:        x coordinate of upstream end (= -31.25,-31.25),  
 XD:        x coordinate of downstream end (=20.75, 20.75),  
 ZU:        z coordinate of upstream end(6.5, -6.5),  
 ZD:        z coordinate of downstream end(=6.6988, -6.6347),  
 CPU:       upstream pressure coefficients (-.0080, .0274),  
 CPD:       downstream pressure coefficients (= -.0028, .0015),

UT:       = u velocity on top wall (19\*0.0),  
VT:       = v velocity on top wall (19\*0.0),  
UB:       = u velocity on bottom wall (19\*0.0),  
VB:       = v velocity on bottom wall (19\*0.0),  
UU:       = u velocity on upstream end (2\*0.0),  
UD:       = u velocity on downstream end (2\*0.0),  
VU:       = v velocity on upstream end (2\*0.0),  
VD:       = v velocity on downstream end (2\*0.0),  
DZT:      = reserved for future use (19\*0.0),  
DZB:      = reserved for future use (19\*0.0),  
\$END

# Results for Example 1:

TEST : 999  
RUN : 999

NASA LANGLEY 0.3-M TCT  
ADAPTIVE WALL TEST SECTION

POINT: 999  
MACH : .501

TOTAL T= 540.00 R  
UINF = 556.97 FPS

NO	X	CPT	ZT	X	CPB	ZB
1	-29.875	-.0080	.0000	-29.875	.0275	.0000
2	-24.625	.0012	.0267	-24.625	.0102	.0075
3	-18.875	.0028	.0656	-18.875	.0112	.0116
4	-13.875	.0021	.1111	-13.875	.0148	.0300
5	-9.875	-.0166	.1800	-9.875	.0144	.0307
6	-6.875	-.0051	.2271	-6.875	.0311	.0307
7	-4.875	-.0297	.2801	-4.875	.0133	.0197
8	-3.375	-.0449	.3186	-3.375	.0278	.0152
9	-1.875	-.0575	.3518	-1.875	.0230	.0095
10	-.375	-.0701	.3779	-.375	.0288	.0068
11	1.125	-.0741	.3909	1.125	.0367	.0048
12	2.625	-.0626	.3870	2.625	.0551	.0102
13	4.125	-.0509	.3694	4.125	.0386	.0069
14	6.125	-.0304	.3417	6.125	.0378	.0017
15	8.125	-.0180	.3129	8.125	.0310	-.0126
16	10.125	-.0118	.2930	10.125	.0271	-.0330
17	13.125	-.0268	.2762	13.125	.0071	-.0662
18	17.125	-.0084	.2471	17.125	.0064	-.1104
19	22.125	-.0029	.1988	22.125	.0016	-.1347

## CALCULATED INTERFERENCE QUANTITIES:

-----  
DELTA M ----- = -.00176  
CORRECTED MACH NUMBER = .49937  
CORRECTION TO AOA (DEG)= -.01507



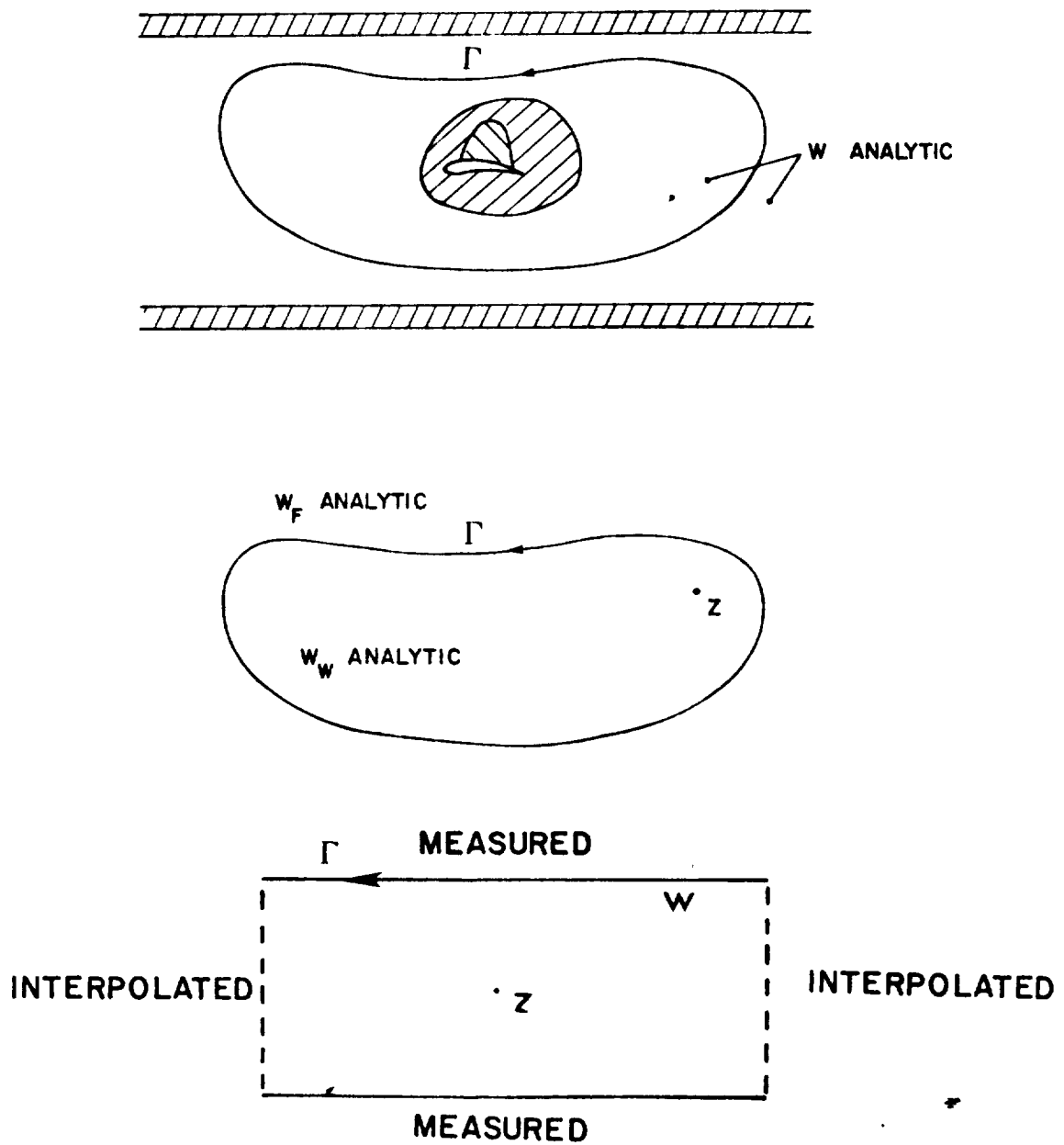


Figure 1: Contour for evaluating the wall interference using Cauchy's integral formula.

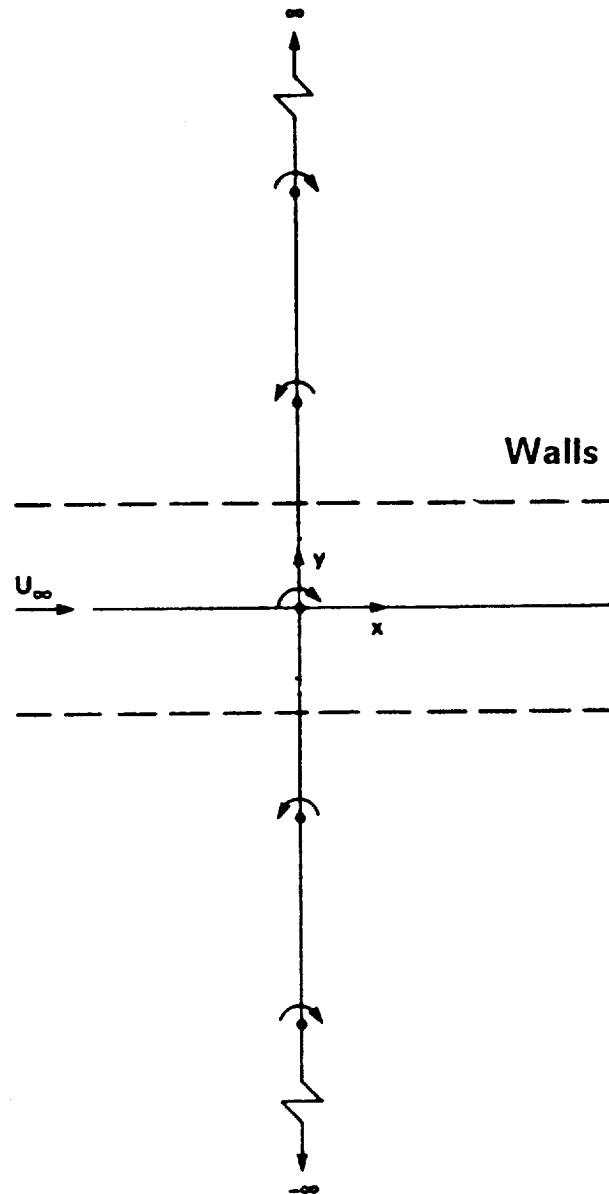
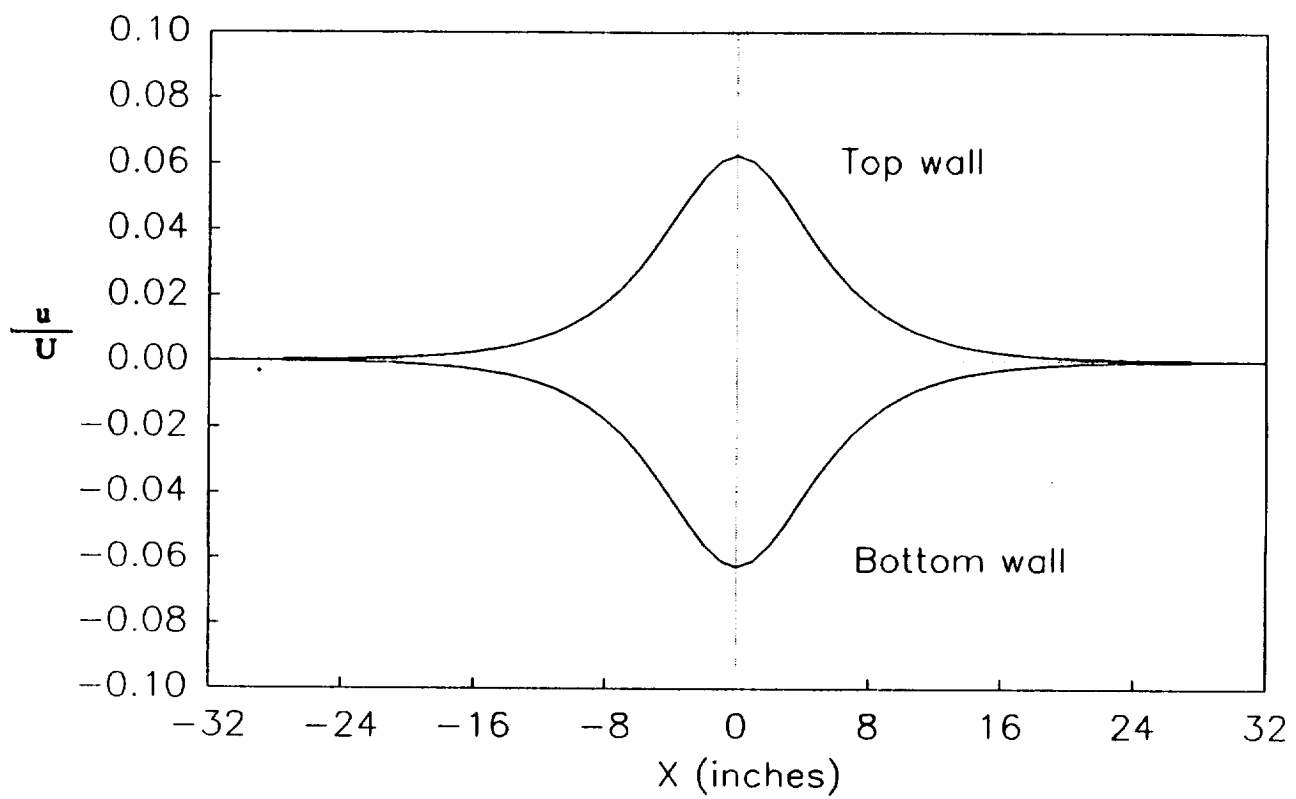
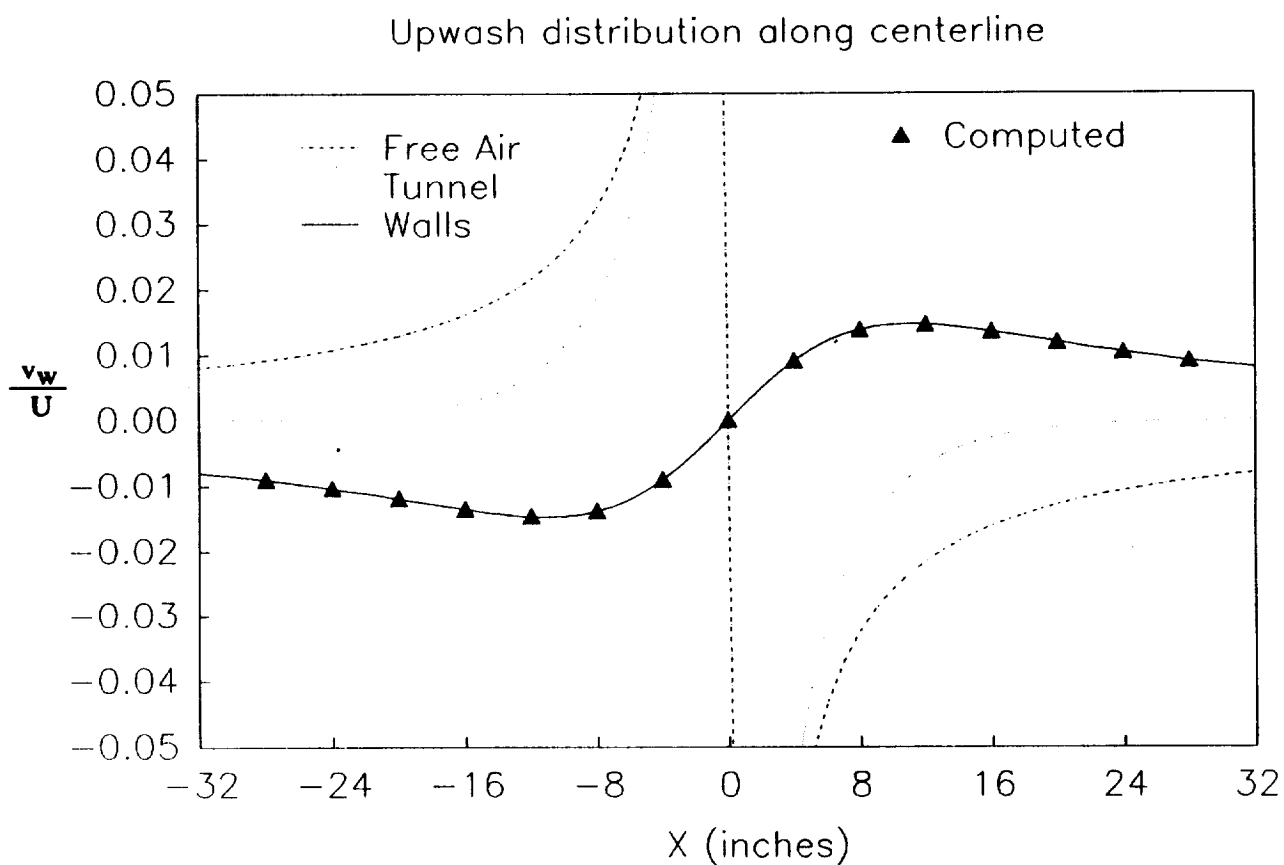


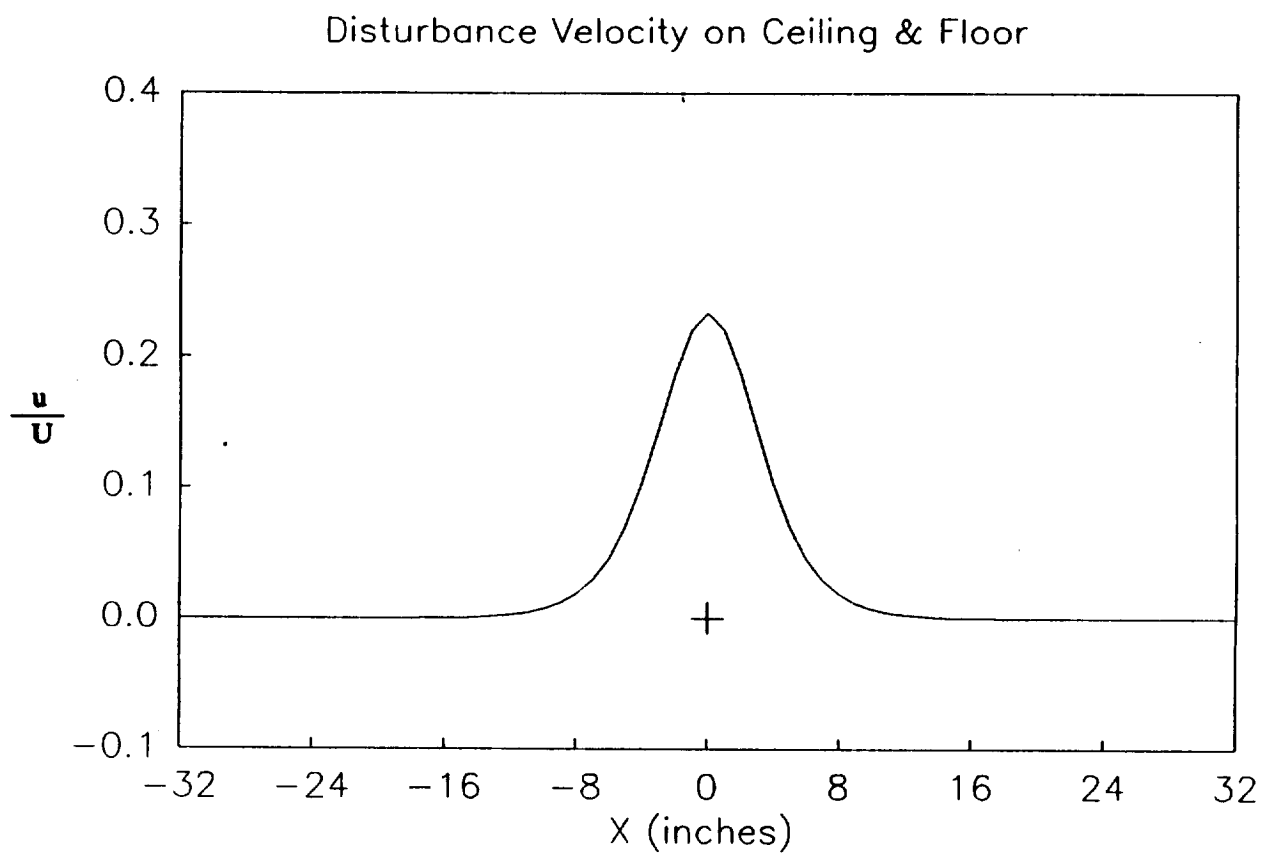
Figure 2: Doubly infinite image system for a vortex placed midway between two horizontal walls.



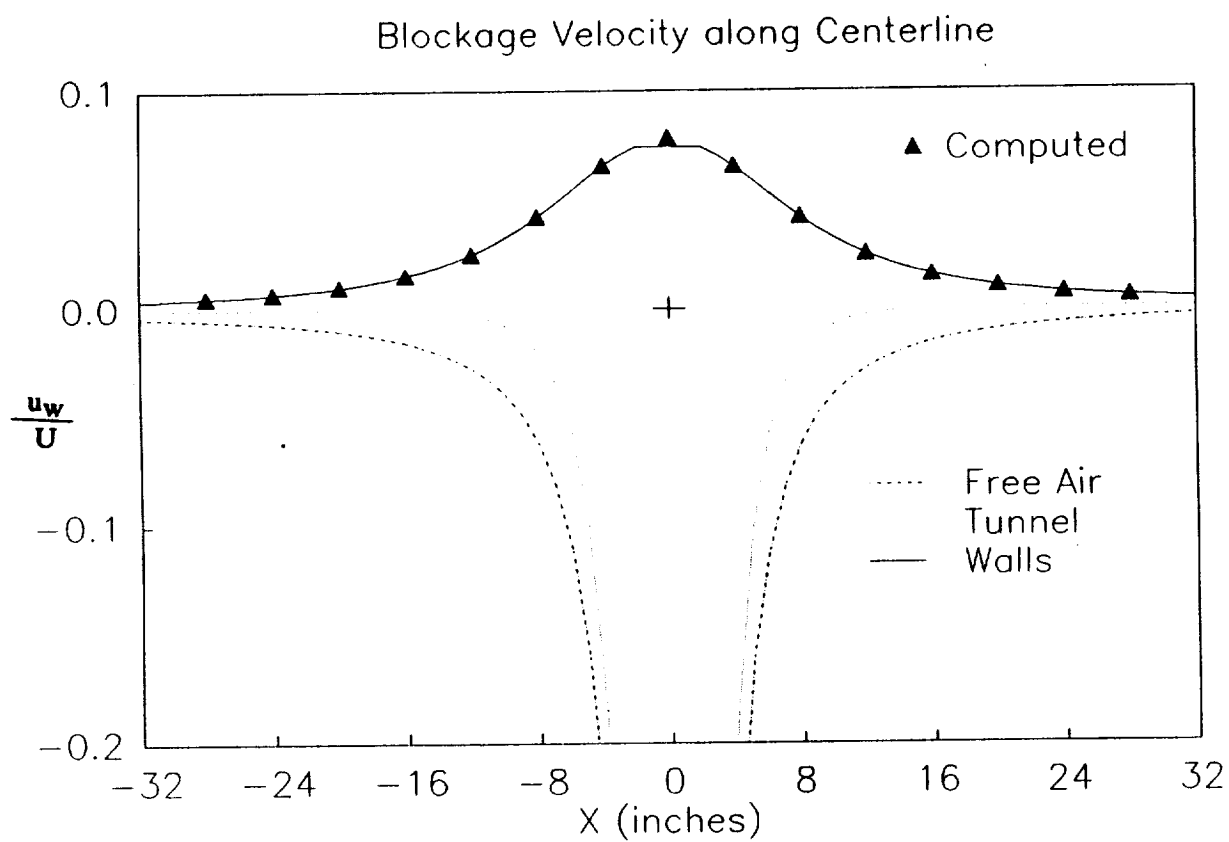
**Figure 3: Velocity distribution on the top and bottom walls due to a vortex placed midway between the walls ( $c=6.5''$ ,  $h=13.0''$ ,  $c_l$ ,  $U_\infty=100$  fps).**



**Figure 4:** Comparison of computed the upwash distribution on the centerline using the wall velocities with exact calculations for a vortex between two walls ( $c=6.5''$ ,  $h=13.0''$ ,  $c_l$ ,  $U_\infty=100$  fps).



**Figure 5: Velocity distribution on the top and bottom walls due to a doublet placed midway between the walls (cylinder radius=2.0", h=13.0",  $U_{\infty}$ =100 fps).**



**Figure 6: Comparison of computed blockage velocities on the centerline using the wall velocities, with exact calculations for a doublet between two walls (cylinder radius=2.0",  $h=13.0"$ ,  $U_{\infty}=100$  fps).**

# 0.3-m TCT ADAPTIVE WALL TEST SECTION

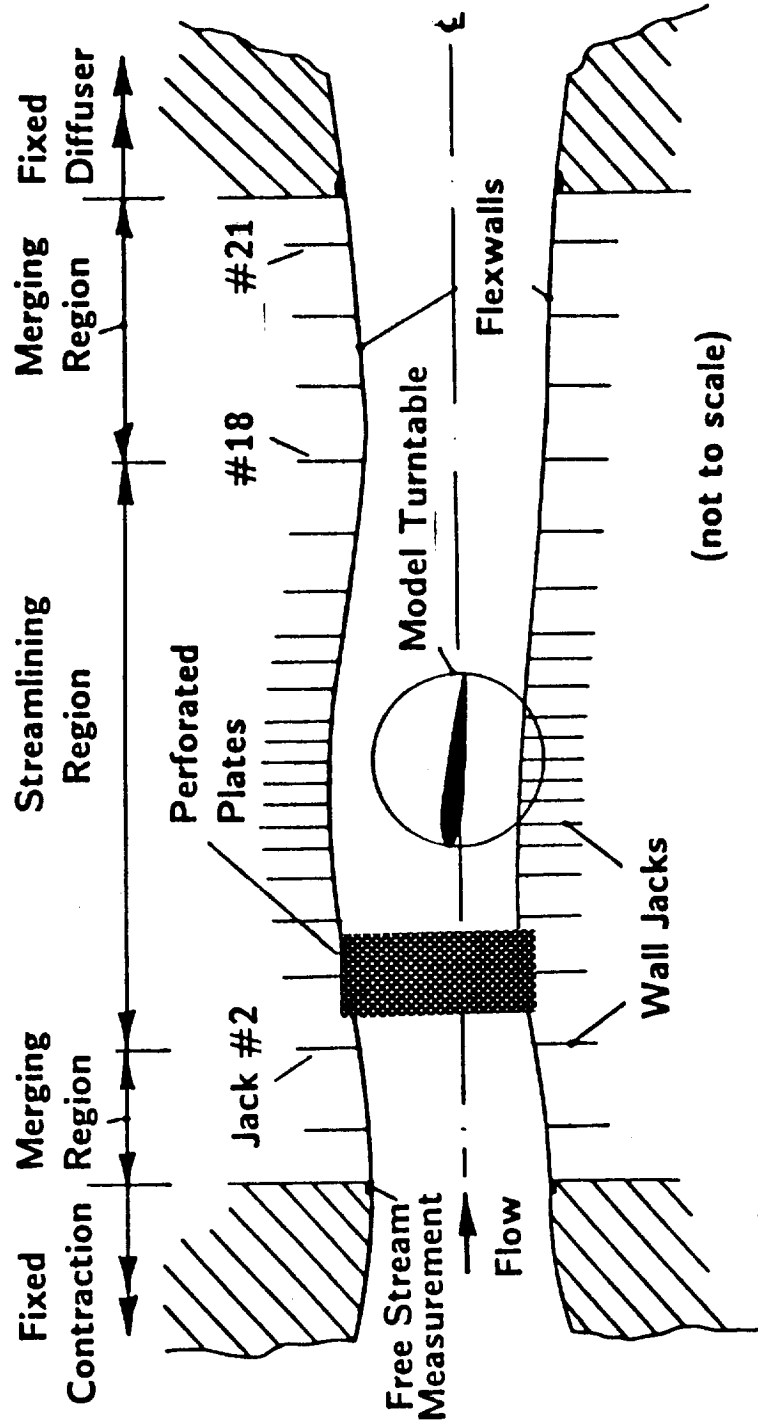
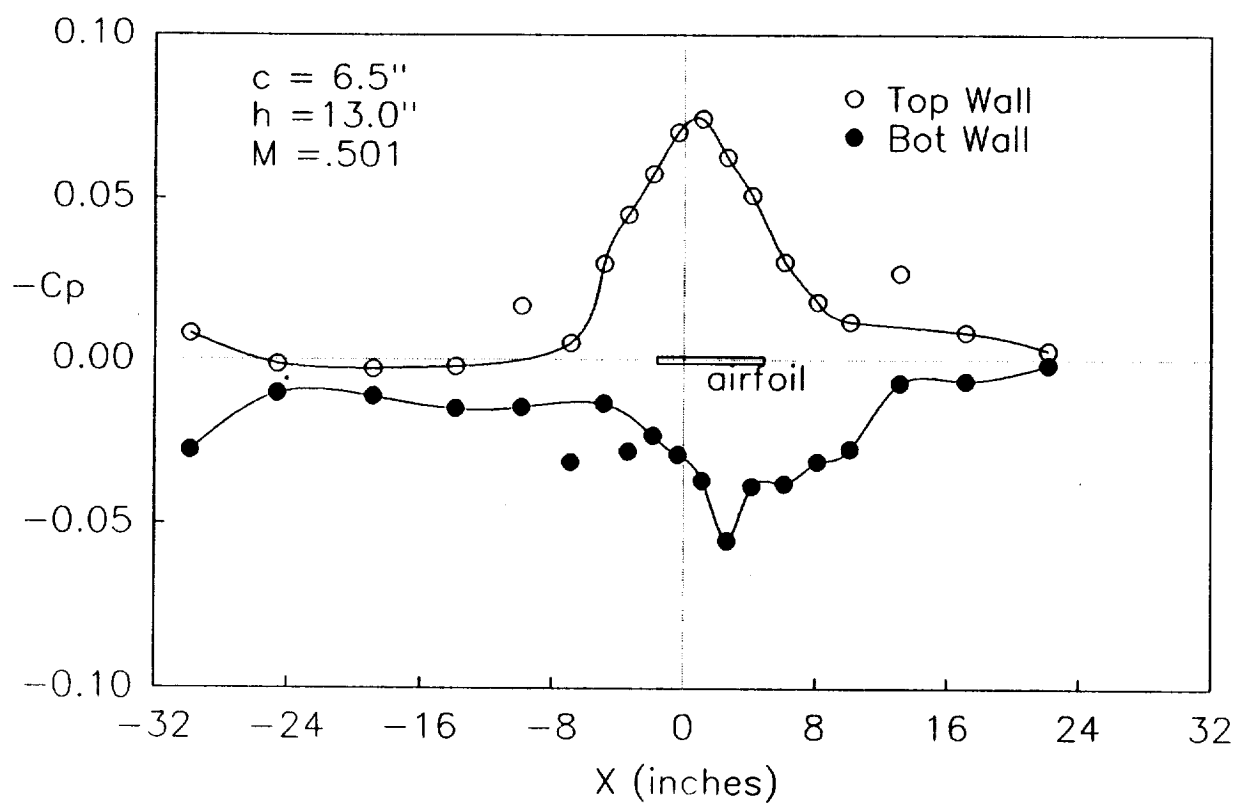
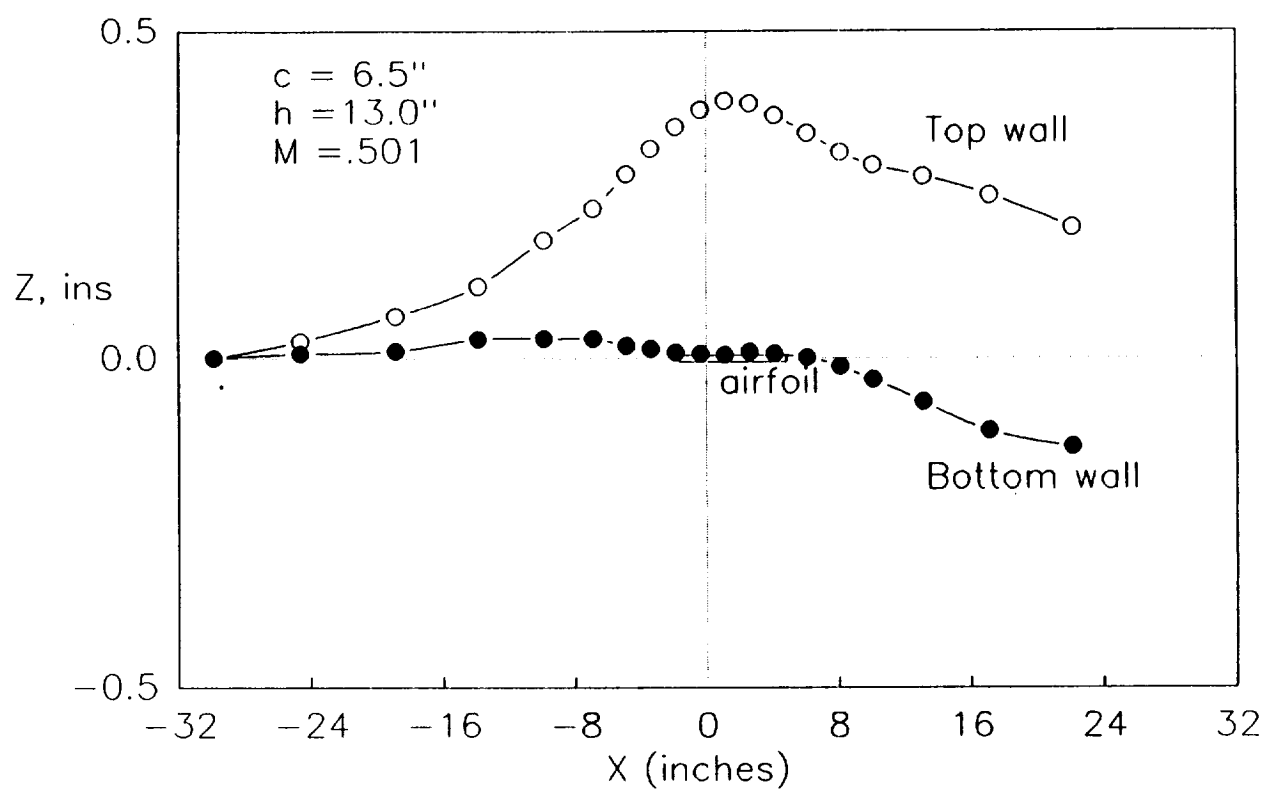


Figure 7: Schematic layout of the 0.3-m Transonic Cryogenic Tunnel Adaptive Wall Test Section.

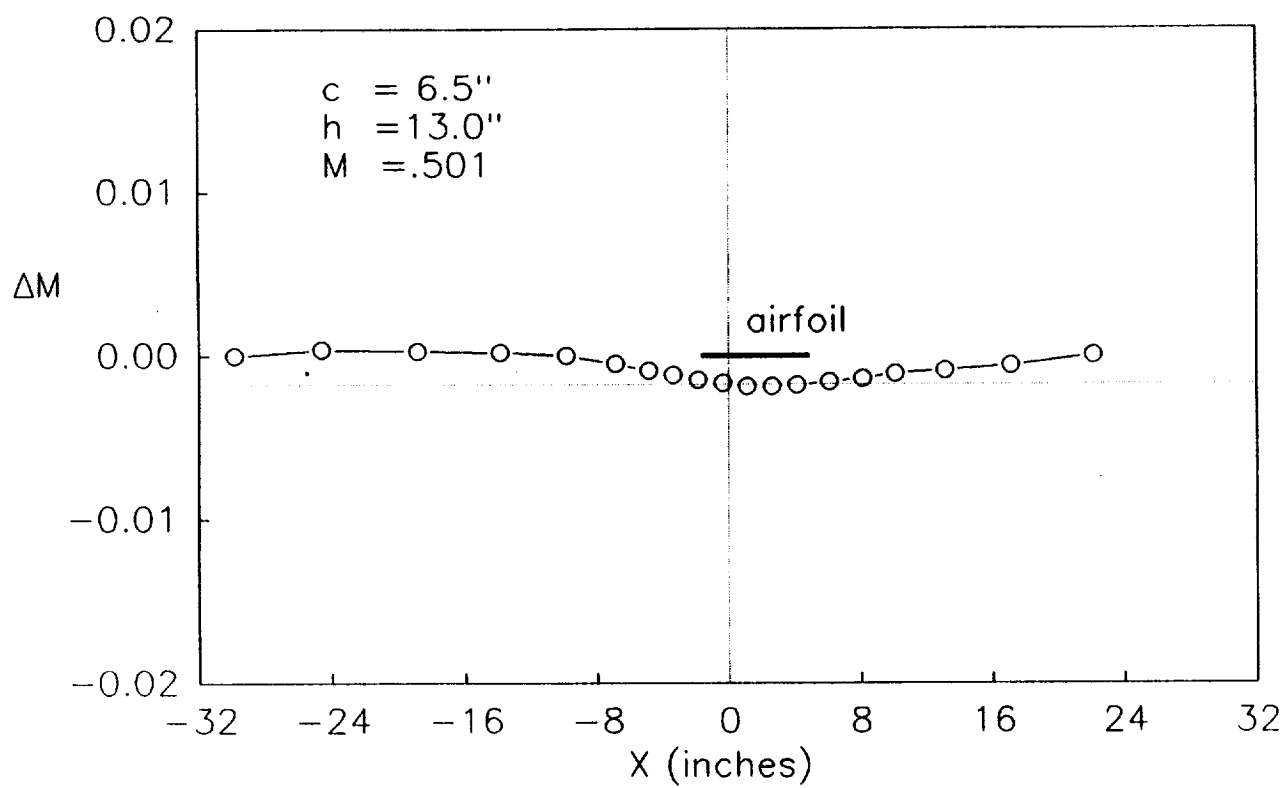


**Figure 8a: Measured top and bottom wall pressure coefficients with a 6.5" chord airfoil (Example 1) ( $M = 0.5$ ).**

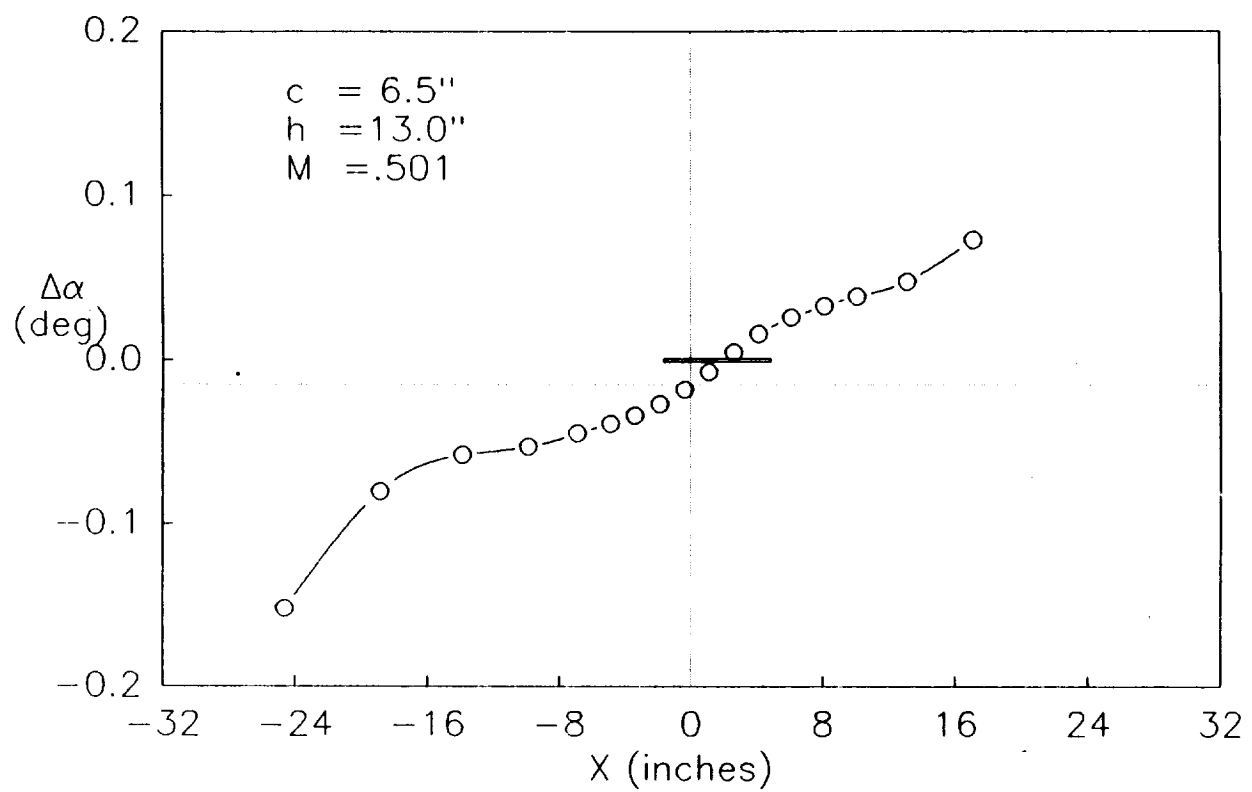




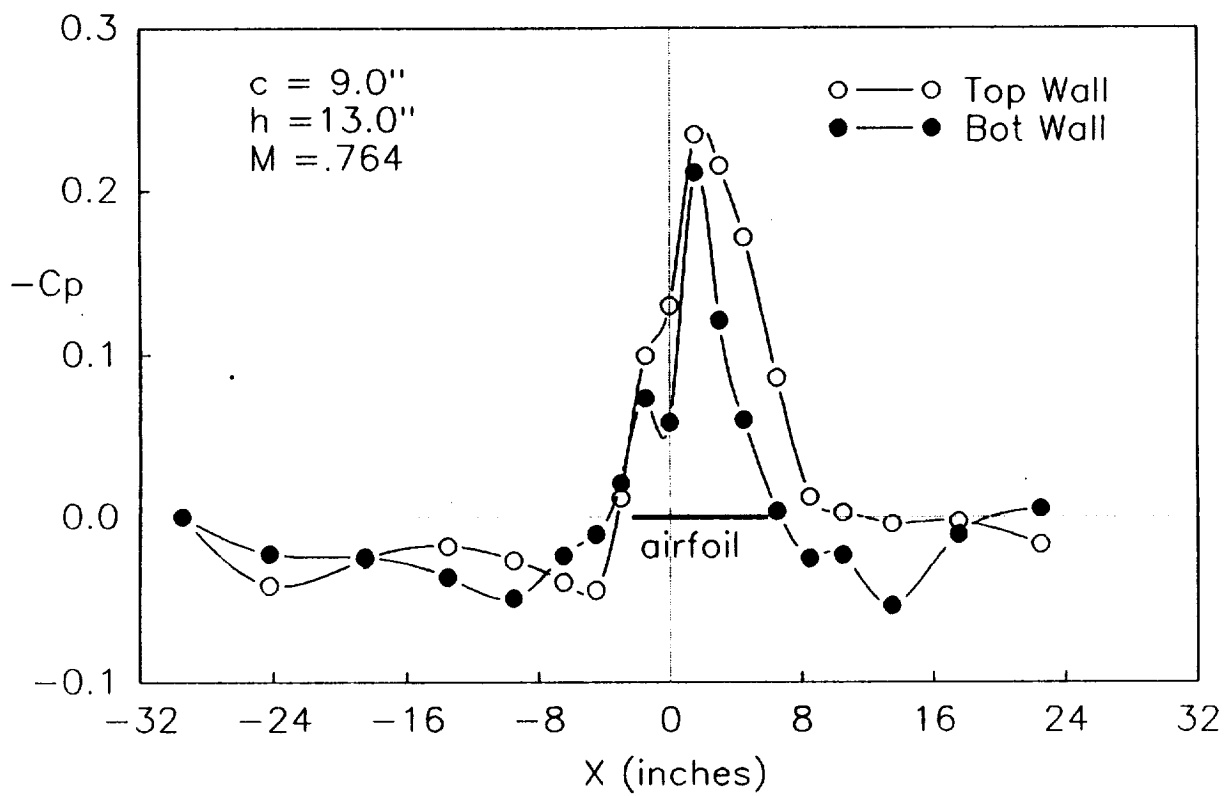
**Figure 8b: Top and bottom wall contours for the walls streamlined condition for Example 1.**



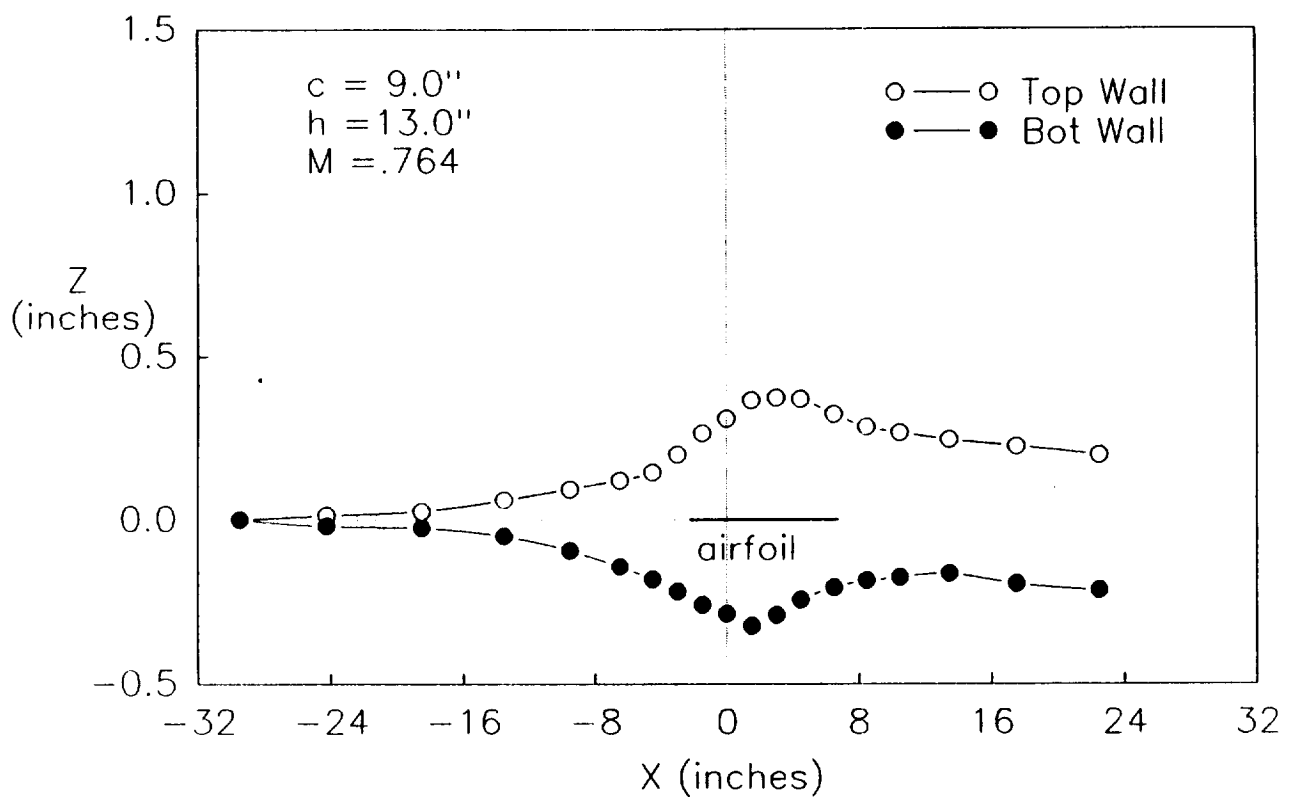
**Figure 9a: Calculated blockage correction for the test Mach number along the tunnel centerline for Example 1.**



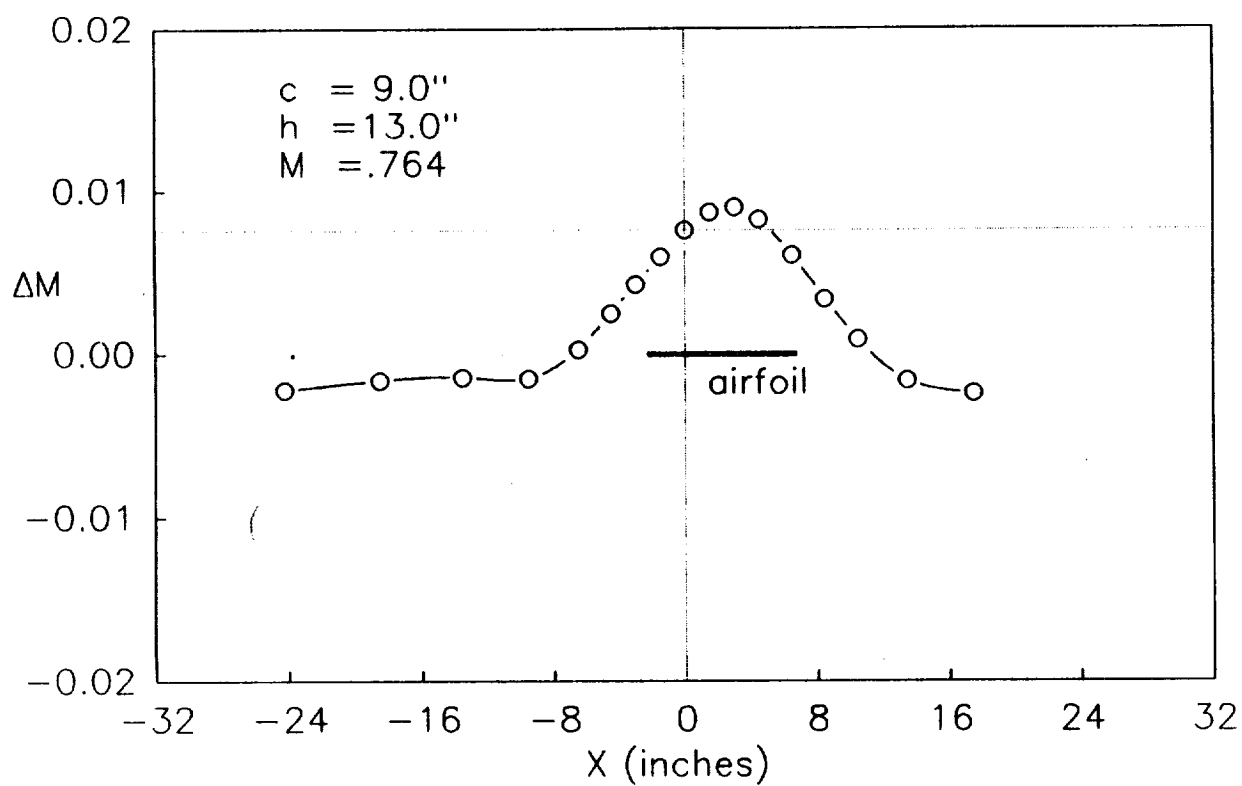
**Figure 9b: Calculated upwash distribution along the tunnel centerline for Example 1.**



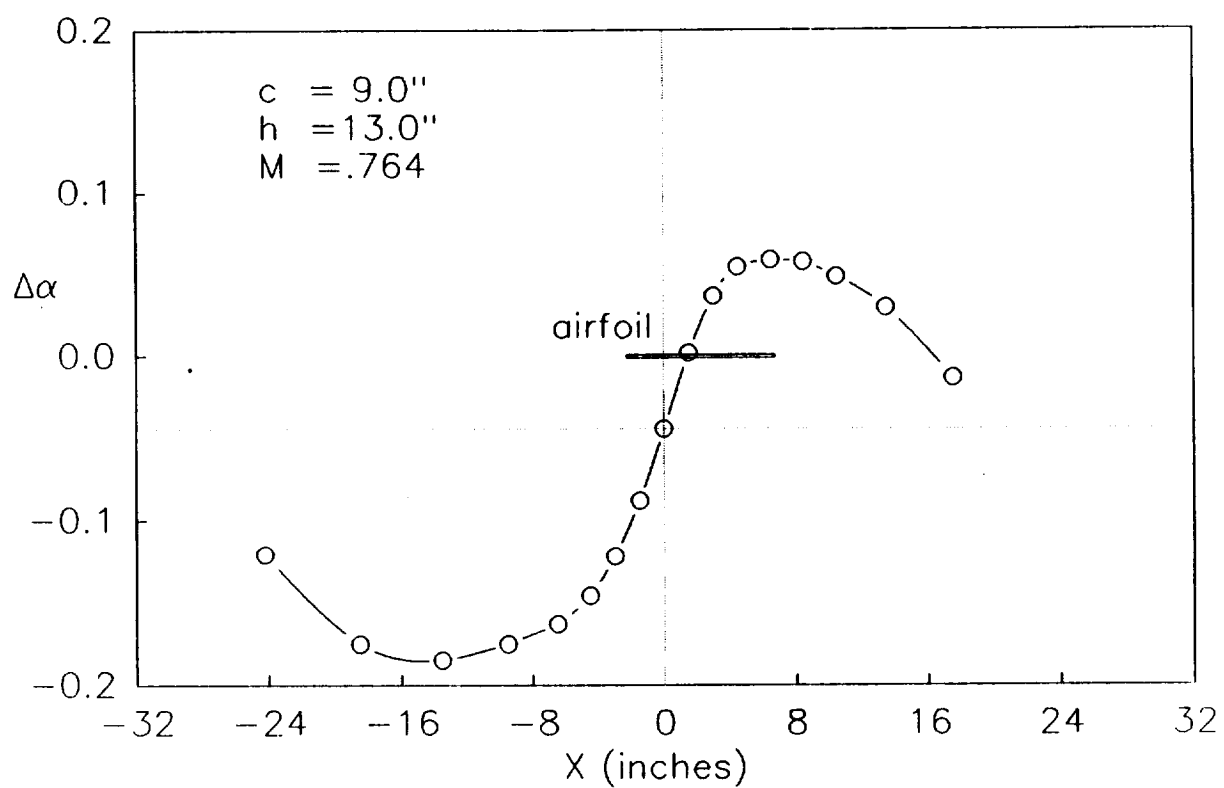
**Figure 10a: Measured top and bottom wall pressure coefficients with a 13.0" chord supercritical airfoil (Example 2).**



**Figure 10b: Top and bottom wall contours for the walls streamlined condition for Example 2.**



**Figure 11a: Calculated blockage correction for the test Mach number along the tunnel centerline for Example 2.**



**Figure 11b: Calculated upwash distribution along the tunnel center-line for Example 2.**



## Report Documentation Page

1. Report No. NASA CR-181896		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle  Residual Interference Assessment in Adaptive Wall Wind Tunnels				5. Report Date September 1989	
				6. Performing Organization Code	
7. Author(s)  A. V. Murthy				8. Performing Organization Report No.	
				10. Work Unit No. 505-61-01-09	
9. Performing Organization Name and Address Vigyan Research Associates, Inc. Hampton, VA 23666-1325				11. Contract or Grant No. NAS1-18585	
				13. Type of Report and Period Covered Contractor Report	
12. Sponsoring Agency Name and Address  National Aeronautics and Space Administration Langley Research Center Hampton, VA 23665-5225				14. Sponsoring Agency Code	
15. Supplementary Notes  Langley Technical Monitor: Edward J. Ray					
16. Abstract <p>This paper presents a two-variable method suitable for on-line calculation of residual interference in airfoil testing in the Langley 0.3-Meter Transonic Cryogenic Tunnel (0.3-M TCT). The method applies the Cauchy's integral formula to the closed contour formed by the contoured top and bottom walls, and the upstream and downstream ends. The measured top and bottom wall pressures and position are used to calculate the correction to the test Mach number and the airfoil angle of attack. Application to specific data obtained in the 0.3-M TCT adaptive wall test section demonstrates the need to assess residual interference to ensure the desired level of wall streamlining is achieved. A Fortran computer program has been developed for on-line calculation of the residual corrections during airfoil tests in the 0.3-M TCT.</p>					
17. Key Words (Suggested by Author(s))  Adaptive wall wind tunnels Cryogenic tunnels Transonic tunnels Two-dimensional tunnels			18. Distribution Statement  Unclassified - Unlimited  Subject Category 09		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of pages 30	
				22. Price A03	